Goldfields Water Supply Centenary 1903—2003

The Coolgardie Pipeline: 100 Years of Service

Leigh Fletcher

Preparing joints for machine caulking, c 1900, Mephan Ferguson Album

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THE GOLDEN PIPELINE
A NATIONAL TRUST PROJECT

The Coolgardie Pipeline: 100 years of service

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Abstract

In 1896 Sir John Forrest, the Premier of Western Australia and former explorer, asked the Chief Engineer C. Y. O'Connor to estimate the cost of building a reservoir near Perth and pumping water by pipeline 560km to the goldfields at Coolgardie. O'Connor's estimate, made before survey or design, was £2.5m. In 1903 the pipeline was commissioned capable of delivering 23ML/day against a total head of 809m using 8 steam powered pump stations with a capacity of 4.5MW. The final installed cost was £2.6m, of which £1.9m was for the DN750 pipeline.

The pipeline was more than ten times longer than any that had then been built anywhere in the world. If the riveted pipe of the time had been used, the leakage allowance would have exceeded the design flow, and the incremental cost of the extra steel needed because of the low joint efficiency of riveted pipe would have been substantial. The hydrology and geology of the catchment was unknown, and this was only some few years after the introduction of the basic open hearth process made suitable steel available at affordable prices. All of the steel, the cement for the dam wall, and the pumps had to be brought from Europe and North America, and this could not reasonably have been achieved had it not been for the success of the new harbour at Fremantle which had just been controversially built by O'Connor against advice that it could not be done.

The locking bar system for the pipe seams was an Australian invention by Mephan Ferguson, and the quoted price for the supply of the pipe from the two Australian bidders Hoskins and Mephan Ferguson was around half of the next lowest tender. The lead caulked girth joint was also invented for the project.

The project was a pioneering achievement in pipeline technology. It is still in service, with a good deal of the original pipe intact, 100 years after commissioning, and is an example of the importance of far sighted leadership and innovation in the creation of the infrastructure needed for a healthy economy and regional growth. The flow-on economic benefits of the pipeline can be understood by the fact that already by around 1905 some £25m of gold had been produced, and a population of 50,000 was supported in a region where prior to the construction of the pipeline, water had sold for as much as 2s. 6d. per gallon ($3.30/L at today's prices).

Introduction

The township of Coolgardie in Western Australia is about 350km from the Southern Ocean at Esperance, about 550km from the Indian Ocean near Perth, and is about 430m above sea level.

In 1893, Coolgardie consisted of scattered clumps of tents and huts and bough roofed sheds. There were no services: no bank, no schools, no telegraph, no railway, and no coach service [1].

In June 1893 Paddy Hannan, an Irish born prospector who had worked as a gold miner in eastern Australia and New Zealand, discovered gold at Mount Charlotte about 40km from Coolgardie. The gold rush that this precipitated formed the basis for the development of a gold-mining industry in Kalgoorlie which is still sustained well over 100 years later.

Apart from its remoteness and lack of services, the principal problem the early miners faced was a lack of water. The gold was separated by a process called dry blowing which involved shovelling the earth into the air and relying on the wind to blow the lighter earth away from the gold.

The rainfall was low and highly unreliable. The recorded annual falls at that time varied between 90 and 260mm [2]. There were no surface supplies of fresh water and attempts to locate artesian water were not successful.

A rainfall map of the locality with the route of the pipeline superimposed upon it is shown in figure 1.

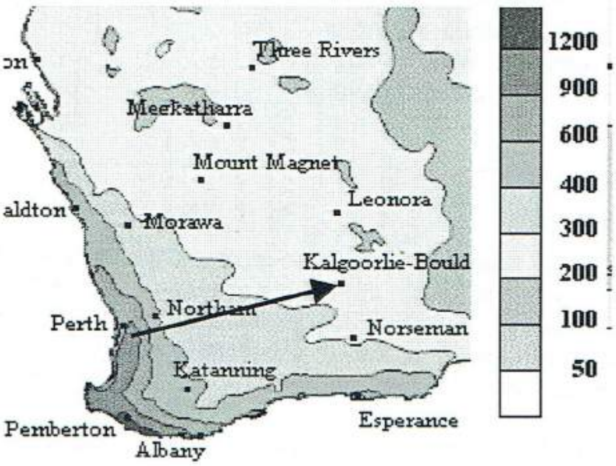

Figure 1 A map of the locality of the pipeline showing the annual rainfall in mm [3]. The position of the pipeline is shown with an arrow.

No permanent gold town of any size had ever been established in an area with effectively no water supplies. Quite apart from the needs of the population, large quantities of water are required for the mining and ore beneficiation processes [1].

The Chief Engineer

The Chief Engineer of Western Australia at the time was C.Y. O'Connor [4]. O'Connor was appointed from New Zealand in 1891 by the Premier Sir John Forrest, and was a very important figure in the history of Western Australia and the driving force behind the Coolgardie Pipeline.

The need for an augmented water supply

There is no doubt that there was a need for an augmented water supply if the goldfields region was to be developed. Drinking water was extremely expensive. In times of drought a gold miner needed perhaps a quarter ounce of gold just to pay for a week's drinking water [1]. At the current price of gold in 2002 of around US$320 per ounce (Aust$580), this is $145/week just for enough warm, brown, and brackish water to drink to stay alive. So, for people to live and work in the region, and for the water necessary for mining, which after all is what the people were there for, some additional source of water was necessary.

Relative costs

According to the Reserve Bank of Australia [5] the consumer price index in 1898 was 2.33, whilst in March 2002 it was 137. The ratio of prices, or relative cost, is thus a multiple of approximately 60, with an additional factor of two for the change from £ to $. At this rate, the estimated total project cost referred to in the abstract of £2.5m, is equivalent to $300m Australian in 2002.

By modern standards this seems to be quite low. The pipe alone, albeit with a better corrosion protection system, would probably cost around $100m, and using a rule of thumb multiplier of three this would produce a budget price of around $300m for the pipeline without the dam.

The choices for augmentation

The available choices of methods of augmentation of the water supply in the Coolgardie area were:

(a) finding and developing an artesian source i.e. a bore;
(b) expanding the practice of using wood-fired desalination boilers which was the main existing source of drinking water;
(c) carrying water by rail;
(d) building a dam to trap water in a local catchment; or
(e) building a pipeline.

Serious attempts were made to find artesian water without success. Desalination was too expensive, it used huge quantities of timber for fuel, and was incapable of supplying the required volumes.

Great private and public effort was expended in the desalination of water in the wood fired boilers. A small private operation is shown in figure 2.

Figure 2 A small private water desalination boiler in operation in Coolgardie in 1895 [6].

Carrying water by rail simply did not work because the locomotives used almost all of the carted water just to get there and return. And the option of building a dam was not a serious one

because of the unreliable rainfall, the high rates of evaporation, and the lack of worthwhile run-off.

The choice of a pipeline

It has been argued by Blainey [1] that the rainfall records available at the time the pipeline was designed were not properly considered, and the same author has put forward an argument that instead of the pipeline, a dam might have been used along the lines of the water supply that was developed for Broken Hill. Blainey considers that whilst the designer of the pipeline, C.Y. O'Connor, may have been the subject of excessive criticism and political pressure at the time the pipeline was built, that he was less than rigorous in the public justification of the pipeline option, and especially the design capacity that was chosen. Blainey claims that long after the troubles that O'Connor experienced during his lifetime, that the pendulum has swung too far in the opposite direction and that nowadays O'Connor is unjustifiably venerated.

According to Hartley [7], Blainey's claim that a dam would have served instead of a pipeline does not stand critical scrutiny, or the experience of 100 years since the decision was taken. This is proved by the sustained and continuing demand for water from the pipeline for over 100 years.

The choice of pipeline capacity

In 1895 or 1896, any estimate of the amount of water needed by the mines in a year's time could only have been a guess [2], and a prediction of the needs after the three years that it would take to build the pipeline would have been even less well founded.

When O'Connor asked the Mines Department to request its Wardens to estimate how much water the mines would be likely to purchase, only one replied, and his comment was that he was unable to make a worthwhile estimate.

The subject of the pipeline capacity is complex, and because the actual delivered quantity never approached more than about 20% of design capacity in the early years of the service of the pipeline, is also somewhat controversial. Blainey's argument relating to capacity obviously has some merit when the benefit of hindsight is applied. However, as Hartley [2] has pointed out, the chief flaw in Blainey's argument is that he criticised O'Connor for over-supplying the needs of the mining industry in 1903, whereas O'Connor had to decide on the delivery capacity of the pipeline seven years earlier in 1896.

Whatever the merits of Blainey's retrospective criticism, O'Connor's design was carefully executed, rigorously examined by a Commission of Engineers appointed for the purpose, implemented on time and within budget, and has stood the test of 100 years of service. It is also probable that O'Connor was inclined to be prudent in the choice of capacity. The design was after all totally novel. No such pipeline had ever been built anywhere in the world, and as such there were many unknown factors such as leakage and internal fouling which were expected to influence the performance of the pipeline in operation [2].

It appears that, along with the very decision to build or not to build the pipeline, the supply capacity was something that O'Connor responded to at least in part as a political decision rather than something that he as the Engineer alone determined. This view is given weight by the statement in the Interim Report of the Commission of Engineers - a group of eminent engineers from the UK - [8] appointed by the Government of Western Australia that *" ... as the reference to us does not extend to the sufficiency of the supply at the source, we have not taken that subject into consideration, but have confined our enquiry to the best conditions under which 5,000,000 gallons a day may be pumped to a point near Coolgardie ..."*

That report was presented to both houses of the Western Australian Parliament in 1897.

Later on in the life of the pipeline, its capacity was exceeded, and had to be extended by duplication and by the installation of larger diameter pipe.

The sizing and cost of the pipeline scheme

In September 1896, the parliament sanctioned the raising of a loan of £2,500,000 for the construction of a storage reservoir at Mundaring in the Darling Ranges near Perth of 21 gigalitres (GL) capacity, a 750mm (30") nominal diameter (DN750) pipeline throughout the 560km length, and a series of eight pumping stations, with the necessary receiving tanks and distributing reservoirs. The design capacity was 23 megalitres per day (ML/day), giving a storage capacity in the dam of 2.5 years [9].

The novelty of the scheme

In 2002, 107 years after the pipeline was designed, long distance pipelines are commonplace. All of Australia's cities are supplied with water and with natural gas by long pipelines, more than a few of them over 1000km long. So, to

us today, the idea of building a pipeline 560km from Perth to Coolgardie, is not at all surprising. Such things are done all the time, and scarcely rate a mention in the news of today.

However in 1895, this was not the case. There were no long distance pressure pipelines to compare with this proposal anywhere in the world. It wasn't a case of a small step out; it was a total revolution in pipeline technology which in modern times would be viewed as at least high risk, if not downright adventurous. Some of the novel and difficult aspects of the scheme were:

(a) the hydrology of the catchment was both unique and undocumented. According to Deacon (one of the members of the Commission of Engineers) the discharge of the Helena River of only 0.2% of the rainfall was *"astonishing to the English hydraulic engineer"* . The comparable figure for the Thames is 20% [10];

(b) the chosen method of making the pipes, Mephan Ferguson's invention of the locking bar pipe, was then in *"..quite an experimental stage.."* as only a few short pipes had been produced, and those had been made by hand [10]. So not only were the pipes a totally new and untried product at the time of the design, there was moreover no factory or machinery for making them (however by the time the final decision was made three years after the original design, the locking bar system had been demonstrated in practice by the successful construction of a 16km pipeline in South Australia);

(c) the accepted conventional method of making steel pipes at the time was by riveting, and on account of the great length of the pipeline, and the enormous number of rivets involved, it was expected that unacceptable amounts of water would be lost by leakage if riveted pipes had been used;

(d) in fact, at that time, steel pipes were not in common use. On the contrary, the Coolgardie pipeline was the forerunner of what later became accepted practice. Steel, as a bulk material available in very large quantities, was a novel material. The Bessemer process, which was the first method for making steel in tonnage quantities, became available in 1860 only 35 years before [11]. But it was not suitable for producing steel of the quality and quantity that would be needed for the 70,000 tons of plate required. The basic open hearth process, which was capable of producing high quality steel from widely available ores, was a later development, and the Carnegie Steel Company which supplied half of the steel plate required for the job, only established its capability 10 or less years before the pipeline was designed [12]. The same would have applied to the German producers of the other half of the steel plate;

(e) the conventional low risk approach to the construction of pressure pipelines at the time was to use cast iron. However the use of cast iron was out of the question. The manufacturing infrastructure did not exist in Australia, and could not have been created in time or within budget, and the transport of heavy cast iron pipes from the industrialised countries by sailing ship across the sea, and then cross country to the pipeline was ruled out as impossible;

(f) the weir to be constructed at Mundaring was one of the highest in existence [10];

(g) the position of the reservoir was *"exactly the reverse of all reservoirs in England, and of most reservoirs in other parts of the world ... it was situated at the bottom of the distributing system instead of at the top .."* [10] i.e. it required a pumped rising main;

(h) *" .. the length of the rising main and the magnitude of the pumping installation were not equalled in any existing waterworks .."* [10];

(i) the method of making the joints between the pipes in the field using lead caulked sleeves was, along with the pipe, also invented by Mephan Ferguson expressly for the job;

(j) as was to become increasingly apparent over the life of the pipeline, the technology for the protection of thin buried steel pipes against external corrosion, and against internal corrosion simply did not exist; and finally

(k) the very formidable logistical difficulties of building a bold new pipeline scheme in what is still regarded as one of the most remote locations in the world. There was very little infrastructure, and there were formidable communication and transport difficulties. All of the steel, and the cement for the dam came by sailing ship with passage times of three months. The fastest possible passage was by steamer which took two months. The fastest means of communication was by the

overland telegraph which had been linked to Western Australia in 1877. By contrast to the way international business is done today, when O'Connor went to London in 1897 to consult with the Commission of Engineers he was away from his home and office for nine months just at the time when the demands of the pipeline and his many other interests and responsibilities were at their greatest.

To a modern pipeline engineer this is all truly remarkable. And most of all, what marks the times as different to now, is that notwithstanding all of this novelty and challenge, the Commission of Engineers in its final report is reported as saying *"While the scheme, if carried out, will be the largest of its kind in the world, there is nothing in the nature of it, or in any of its details, which is the least degree impractical or unprecedented. And with reasonable care and skill there is no reason to suppose otherwise than that it will prove to be entirely satisfactory.* [4]

And so it turned out on the broad sweep of things. Although, as we shall see, there were one or two matters in the operation of the pipeline over time that were not in the *"... detail ... entirely satisfactory .."*. This was particularly the case in the area of corrosion, and in the related decision to bury the pipeline.

The contracts for the pipes

The Commission recommended that the pipes should be of steel throughout, supported on bolsters, and riveted up in lengths of about 33m, with expansion joints at those intervals, and anchor joints midway. The minimum thickness was to be 4.8mm, and welded rather than riveted pipe was to be used where the pressure containing thickness was greater than 6.4mm [9].

Tenders for the pipes were invited from Australia, Europe and North America, and tenders for alternative materials were allowed.

At the end of the tender evaluation process, the decision was made to use the newly patented locking bar pipe invented by the Australian manufacturer, Mephan Ferguson [13], and to standardise the diameter and thickness of all of the pipes at DN750 and 6.4mm respectively. In most locations the pipe was to be buried, and expansion joints were not employed.

The Australian prices for locking bar pipe were about half those quoted by European suppliers for welded pipe, and were competitive with that of riveted pipe [9]. The lowest tender for riveted pipe was submitted by G. & C. Hoskins [13]. The locking bar pipe brought great advantages. The joint efficiency was 100% as compared to 75% for longitudinally riveted pipe, and so there was a saving of some 20% in the total amount of steel required for the same design head. And the frictional resistance of the locking bar pipe was reckoned to be less by around 25%, which would lead to substantial savings in pumping costs.

Contracts with the two successful Australian tenderers; Mephan Ferguson and G. & C. Hoskins were let in October 1898 [14]. Each contract was for 30,928 lengths of 8.54m pipe. The contract included an assignment of rights to G. & C. Hoskins to use the locking bar method.

Manufacture of the plate

The plate for the pipe was manufactured in approximately equal quantities by the Carnegie Steel company in the USA, and by several German producers; Thyssen & Cie, Aktiengesellschaft de Dellinger, Phoenix Actiengesellschaft der Berghan, and Gewerkschaft Grille Funken & Cie.

The locking bar and joint ring section came from Earl Dudley's Iron works at Tipton Birmingham and Ebbw Vale Steel, Iron & Coal Co. in South Wales.

The 70,000 tons of plate was ordered in 8.54m lengths 1.22m wide. Each pipe was made from two plates which were joined by two locking bars.

The contract [14] specified that the plates and bars be made from acid open hearth steel, however this is contradicted by Palmer [9], who states that basic open hearth steel was used. The latter source is more likely to be correct since the acid open hearth process requires special low phosphorous iron ore of restricted availability for the production of steel with the good ductility that was required for this project.

The steel plate was required to have a tensile strength range of 386 to 450 MPa. By modern standards this is an extraordinarily tight range, and such a specification would be unlikely to be accepted by steel makers today. The tight upper limit was necessary to meet a specification requirement that *" .. the joint must always be fully as strong as the plate ... "*. There was a minimum elongation requirement of 20% in 250mm, and a minimum reduction in area of 45%.

The steel was required to undergo a drifting test in which a 16mm punched hole near the plate edge was drifted out to a diameter of 29mm without sign of fracture. This is an unfamiliar requirement today.

A recent chemical analysis on a sample of pipe and locking bar gave the following results [15]:

Element	Pipe	Locking bar
C	0.048	0.075
P	0.011	0.070
Mn	0.51	0.70
Si	<0.005	<0.005
S	0.10	0.12
Ni	0.031	0.040
Cr	0.008	0.032
Mo	0.002	<0.002
Cu	0.10	0.026
Al	<0.003	<0.003
Sn	0.005	<0.002
Nb	<0.001	<0.001
Ti	<0.003	<0.003
V	<0.003	<0.003
B total	<0.0003	<0.0003
Ca	<0.0005	<0.0005
N	0.0044	0.0125
O	0.0195	Not tested

The results of the chemical analysis show a very low phosphorous content for the pipe steel. This supports the previous suggestion that the plate was made by the basic open hearth process. The locking bar on the other hand is much higher in phosphorous and was probably acid open hearth steel.

In other respects, apart from quite high sulphur levels, the analyses are not dissimilar from modern low carbon steels. The sulphur levels are likely to have only have become important when welding was undertaken.

Photomicrographs of the structure of the pipe and locking bar material are shown in figures 3 and 4.

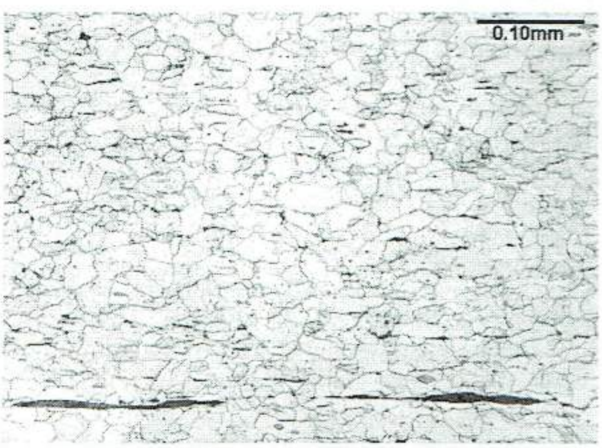

Figure 3 A photomicrograph of the microstructure of the pipe material. The structure is that of a low carbon ferritic steel with stringers of sulphide. [15]

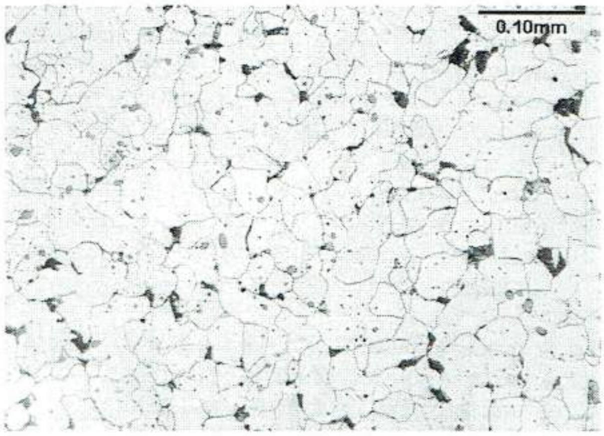

Figure 4 A photomicrograph of the microstructure of the locking bar material [15].

Manufacture of the pipe

In September 1899, less than a year after the award of the contract, two new pipe making factories had been built, new machinery designed, built and installed, and a workforce engaged and trained.

The process for the manufacture of locking bar pipe is depicted in the following photographs reproduced from a copy of an album produced by Mephan Ferguson at the time the pipeline was constructed [16].

As has been mentioned, the locking bar joint was a patented invention of Mephan Ferguson. The seam is not caulked, and is leak free.

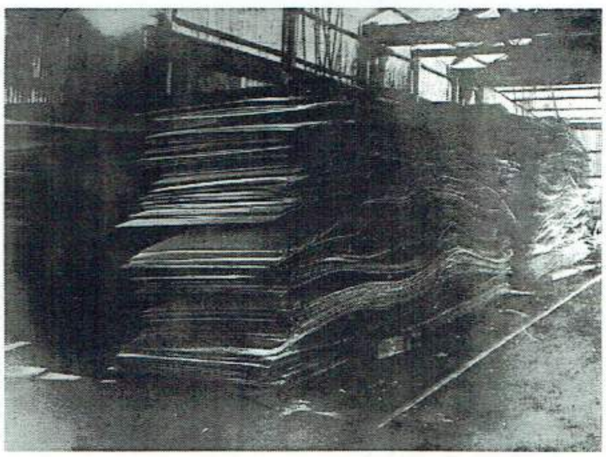

Figure 5 Plates in stacks ready for converting into pipes. The plates were imported from North America and Europe. At first glance the plates seem to be severely out of flat, however this is probably mostly due to the manner of stacking [16].

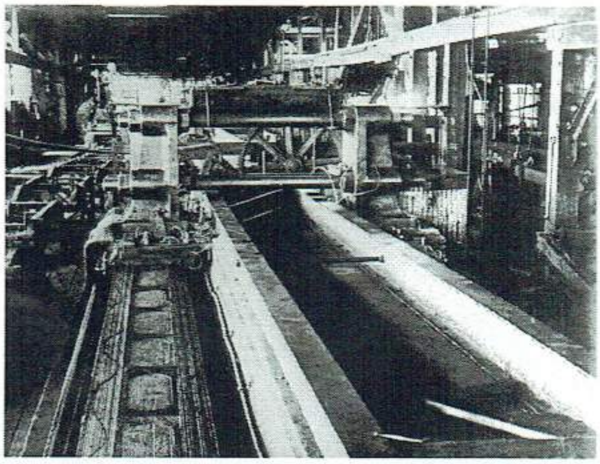

Figure 6 Planing and upsetting edges of the steel plates. The upsetting process causes thickening of the plate edges and forms a dove-tail that provides strength to the joint [16].

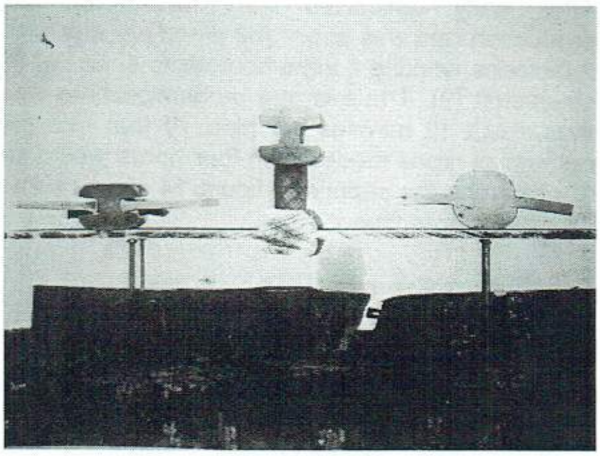

Figure 7 The locking bar joint showing various stages of closure. The locking bar alone is at top centre, the assembled joint ready for closure is on the left, and a closed joint is on the right [16].

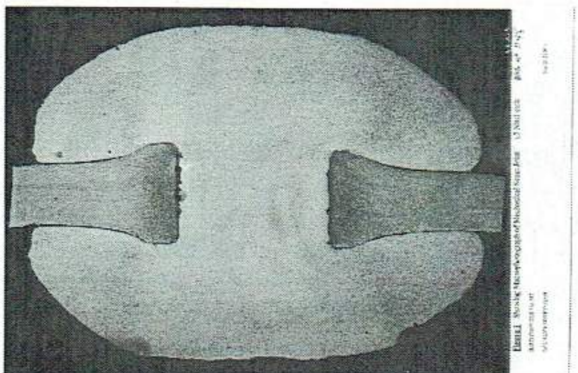

Figure 8 A photomacrograph of the locking bar joint. The dovetails caused by upsetting of the plate edges can be clearly seen. The Nital etch shows the plastic strain in the locking bar caused by closure [15].

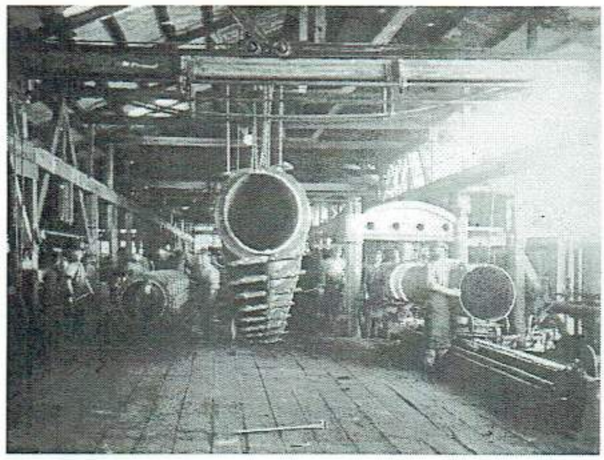

Figure 9 Building the pipe prior to closing the locking bar [16]. The plates were edge-set in a crimping press, and curved into semi-cylinders in a 30' set of triple-backed pyramid bending rolls.

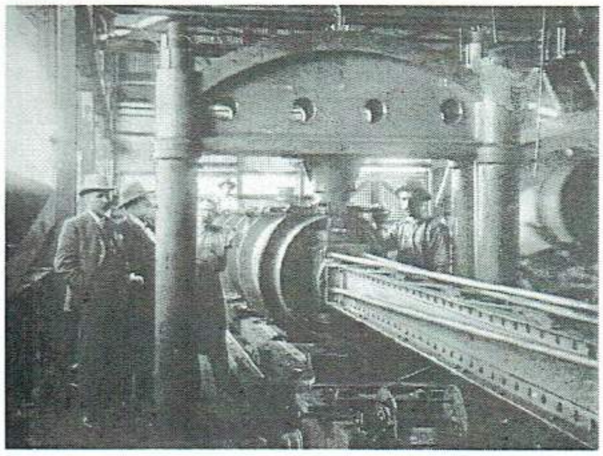

Figure 10 Closing the locking bar in an incremental hydraulic press [16].

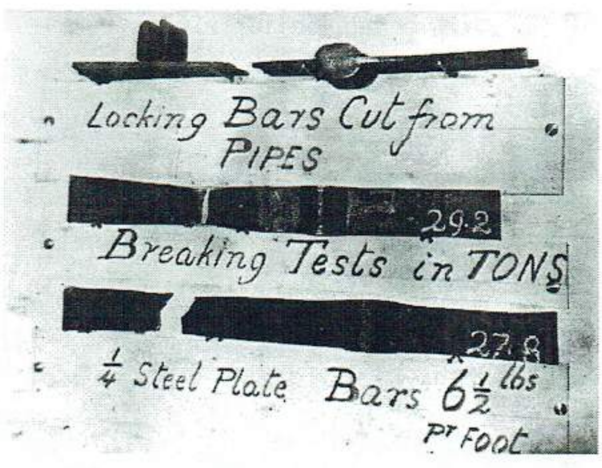

Figure 11 Test pieces cut from the locking bar joint which have been broken in tension. The test pieces have broken in the parent metal of the pipe demonstrating the 100% joint efficiency of the locking bar[16] .

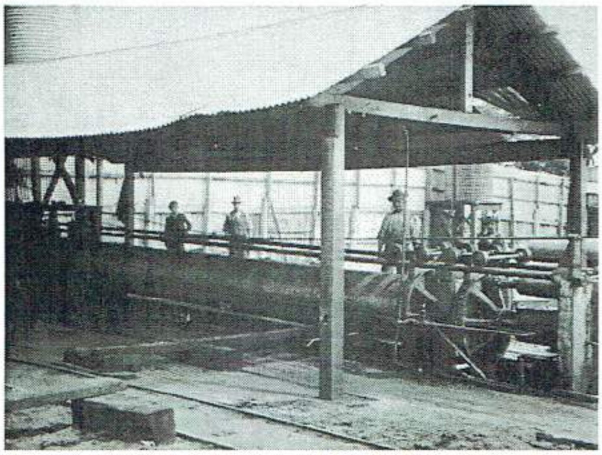

Figure 12 Hydrostatic testing the pipes [16]. The factory test pressure was 2.8MPa compared to a design pressure of 1.46MPa.

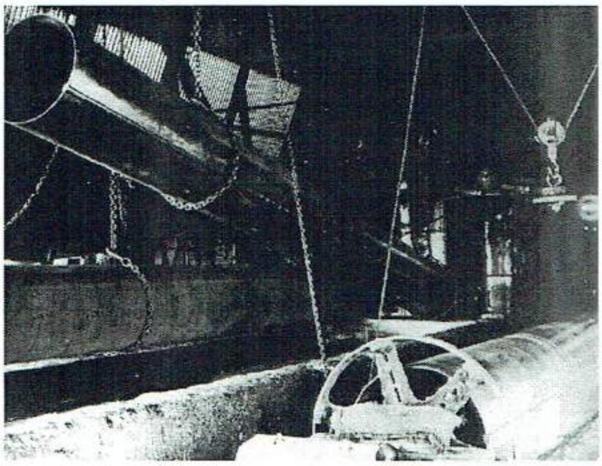

Figure 13 The coating process. The pipes were dipped in molten Trinidad asphalt and then rotated whilst sand was applied to the hot asphalt on the outside of the pipe [16].

Figure 14 A train of pipes ready for delivery to the field [16]. The original caption on the photograph says that the pipes were manufactured in four hours.

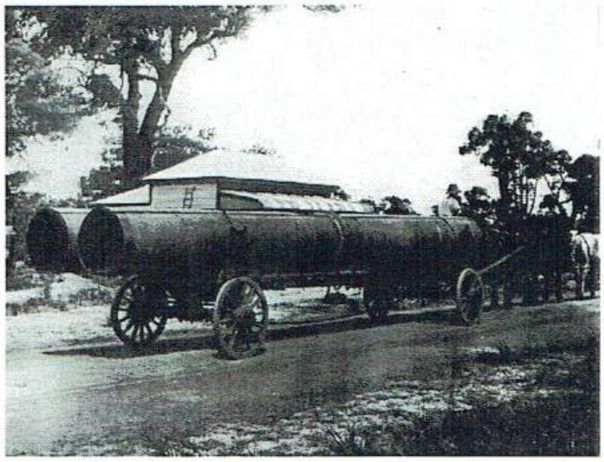

Figure 15 Local delivery of pipes by horse and jinker [16].

After early difficulties were overcome, the production rate was about 160 pipes per day from 2 factories working 2 eight hour shifts each i.e. 40 pipes/shift [9]. The average production time was thus about 12 minutes per pipe. At that rate the number of pipes produced in four hours would be 20, whereas the caption to figure 14 claims some 42 pipes in that time.

Design of the pipeline

The pipeline was designed for a daily flow of 23ML, with an allowance for losses and consumption by the steam engines of 2.7ML, or 12%. The static head was 393m, and the total natural head including the height to be surmounted and losses at reservoirs was 458m [10]. Including friction losses the total head from the dam at Mundaring to the tank at Coolgardie was 809m.

The design stress in the pipe wall was 116MPa, on a design thickness of 6.4mm nominal less a 1.6mm contingency allowance. This gives the design pressure of 1.46MPa.

Placement above or below ground

The decision as to whether to place the pipeline above or below ground was the subject of considerable discussion at the time the pipeline was designed. The Commission of Engineers [8] recommended that it be placed above ground, however according to Palmer [10], their reasons for doing this were not unanimous. One member of the Commission, Professor Unwin, was concerned about the corrosive nature of the soil, whereas another member, Mr. Carruthers, was concerned about the detection of leakage in riveted pipe.

Subsequent to the Commission's recommendation, work was undertaken to analyse the soils along the pipe track. The conclusion of those studies was that for most of the route the soils were not regarded as aggressive, and that the pipeline could be safely buried [9]. At the same time, the selection of the locking bar pipe in lieu of riveted pipe had obviated the fear of leakage, and so these bases for putting the pipeline above ground were no longer imperatives.

The third factor that influenced the decision was the fluctuating temperatures that could be expected in the above ground pipeline due to varying ambient temperatures, exposure to direct radiation from the sun, and from these factors in association with intermittent states of fill in the pipeline. There was scepticism on the part of the Australian design team over the efficacy of the expansion joints proposed by the Commission, and it was thought that whilst the leaded joints should not be exposed to the rigours of above ground use, they would be able to accommodate such thermal movements as would be necessary in below ground service.

According to Hartley [2] it was the large expansion and contraction that would be caused by exposing the pipeline above ground, and presumably the effect of that on the joints, that led O'Connor to the decision to bury the pipeline. This view is consistent with the decision to place the sections which were laid above ground within corrugated steel covers filled with sawdust for insulation.

When, years later in the 1930s, the pipeline was exhumed and re-laid above ground because of severe corrosion, the lead joints were simultaneously removed and replaced by welded circumferential joints.

Also, in the intervening years when substantial lengths of the corroding pipeline were exposed, considerable efforts were made to insulate the regions between the joints so as to minimise the effects of temperature cycling.

On the basis of these observations, there is no evidence that the leaded joints could have survived above ground service. So although there has been at least implied criticism of the original decision to put the pipeline underground, this criticism does not seem to be warranted. The decision appears to have been the appropriate choice at the time it was made.

The pumps

The design provided for eight pumping stations. In the interests of uniformity the first four stations were designed for a lift of 137m each, and the second four for 69m each. The first four were fitted with three pumps, any two of which were capable of performing the work, and the second four had two pumps each, either one of which was sufficient.

The total provided power was 4.5MW of which 1.8MW was reserve.

The contract for the pumps was let to Messrs. James Simpson & Co. Limited of London and the Worthington Company [17]. The engines were horizontal six cylinder, high duty triple expansion, surface condensing steam engines of the Worthington duplex direct acting type [9].

The overall efficiency (coal in to work done on water) achieved by the pumps in test was around 11%. This was a world record for engines of the duplex class [10]. This efficiency compares well with the performance of modern gas turbine driven compressors used for natural gas pipelines where overall efficiencies of between 20 and 25% are usual.

A photograph of one of the pumps is shown in figure 16.

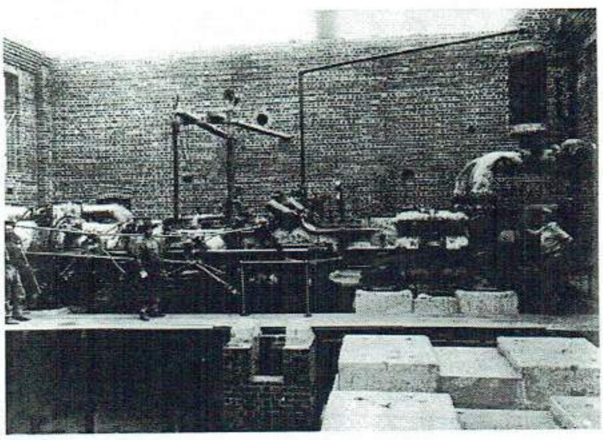

Figure 16 A set of pumps during installation [16]

When the pipeline was first designed it was envisaged that the pumps would be fuelled by coal from the newly opened mine at Collie, however in fact the pumps were operated for most of their life on firewood cut from surrounding indigenous forests.

If this wood had not been used for this purpose, it would still have been cut for the purpose of opening up land for agriculture.

The scale of the usage of timber for firewood can be gauged from figure 17.

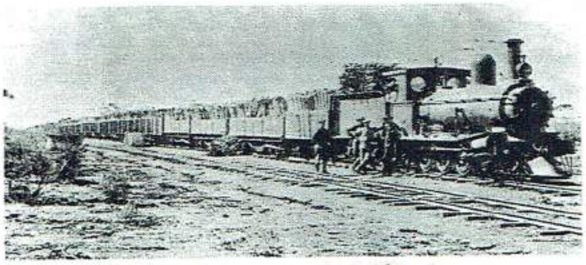

Figure 17 A locomotive hauling a wood train for the Westralia Timber firewood Co. about 1910 [1].

The cost of pumping over the period 1905 to 1915, including all direct costs such as wages and salaries, fuel, repairs and maintenance, and labour overheads was always very close to 5s. per ML lifted. This was less than 1% of the selling price of the water at Kalgoorlie of £44/ML.

The field joints

The pipes were joined in the field with a sleeve joint patented by Mephan Ferguson. The jointing ring was 200mm wide and 13mm larger in diameter than the pipe, and was profiled to allow molten lead to be run into the gap between the ring and the pipe on each side. After the lead had solidified it was then hammered into the joint so as to form a compressed lead annulus between the jointing ring and the outside surface of the pipe to effect a seal.

A series of photographs showing the manufacture of the rings is shown in figures 18 to 20.

Figure 18 The ends of the bars used for jointing rings being scarfed by hand prior to pressing the rings and welding [16].

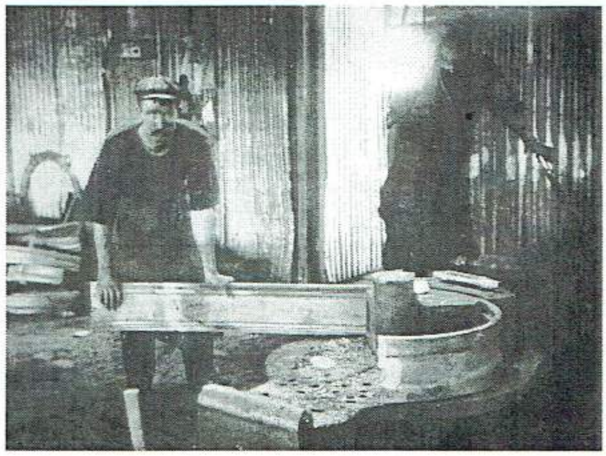

Figure 19 Pressing the rings into cylindrical form [16].

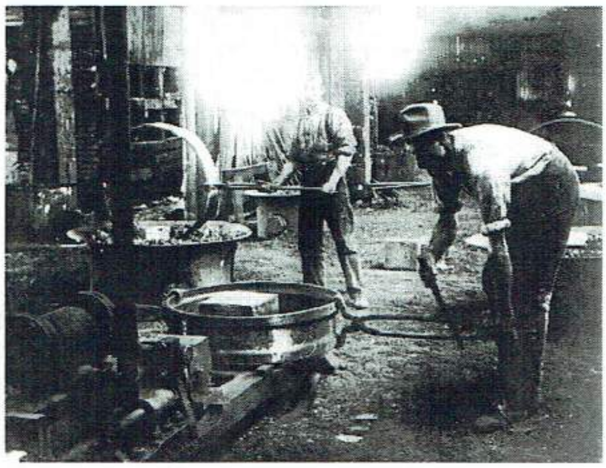

Figure 20 Forge welding the rings [16]. Over 60,000 rings were made in this way.

The method of making the field joint is shown in figures 21 to 24.

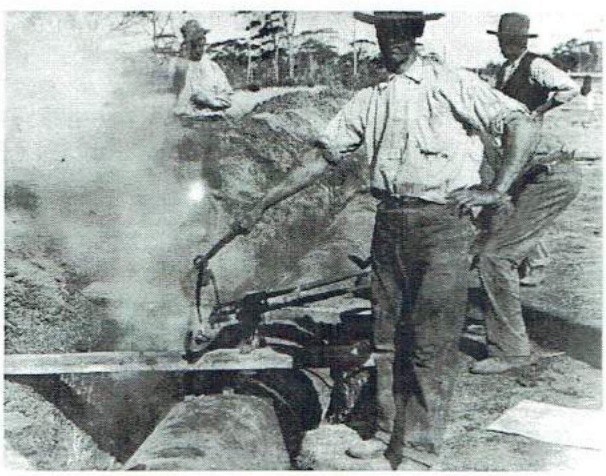

Figure 21 Running hot lead into the joint [16].

Figure 22 Caulking the joints by hand. 8 men could do 25 to 30 joints per day [16].

Figure 23 Later on in the project a mechanised caulking machine was developed driven by a small electric motor powered by a portable diesel driven generator [9,16].

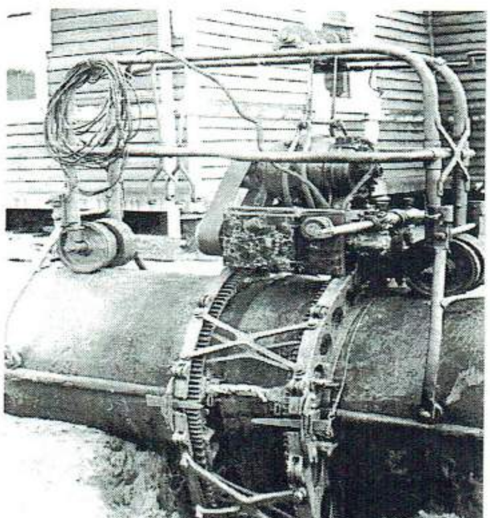

Figure 24 The caulking machine (courtesy Battye Library 3174P)

The finished jointing was judged to be very effective. From the whole length of the pipeline from Mundaring to the last pumping station, the losses were about 2200L per day over 10 months working, and this includes losses due to evaporation and percolation from 9 pumping and break-pressure reservoirs. Since the losses due to evaporation were very substantial prior to the roofing of the reservoirs, a large part of those losses must have been due to evaporation. If the loss per day through the field joints was 1000L, then the average leakage per joint would have been only about 20mL per day.

Corrosion protection

As shown in figure 13, the pipes were dipped in a molten bath of one part asphalt and one part coal tar for the purposes of corrosion protection as part of the manufacturing process in the factory. The formulation of the coating was arrived at after consideration of the wide extremes of temperature from below 0 up to well over 40°C that the pipes would be exposed to [9]. And although the pipeline was designed to be buried, the pipes were required to be suitable for exposure for long periods between manufacture and burial. The same coating material was applied inside and out, except that the outside had sand applied to it whilst still molten to provide a measure of physical and radiation protection.

The method of surface preparation involved passing the plates through a chain flail (Figure 25) as they were straightened prior to edge setting and bending [16]. The various processes of manufacture would have removed loose mill scale and rust, however tightly adherent scale would not have been removed.

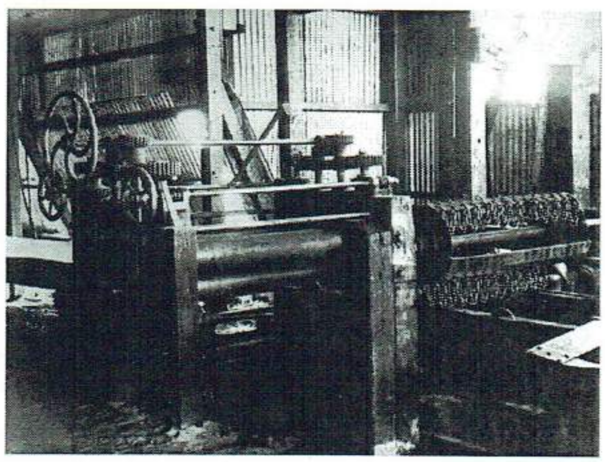

Figure 25 The method of surface preparation for corrosion protection involved the use of a chain flail at the time the plates were straightened before edge preparation [16].

At the time of presentation of the Palmer paper in 1904 [9], which more or less coincided with commissioning of the pipeline, there was comment [10] to the effect that although the paper set out the theoretical requirements for obtaining a good coating, these *"desiderata"* were not to be obtained by the practical means that were employed. The natural asphalt material contained only about 14% of the matter valuable for protecting the pipe, the remainder being composed of mineral matter, mainly calcium carbonate. This, as was pointed out, whilst being perfectly good for paving, which was the major use to which it was normally put, was *".. not only useless, but positively disadvantageous .."* for coating iron for protection against corrosion.

These comments made by Professor Brown [10] were perhaps the most significant of all of the very extensive, technically rigorous, and very stimulating discussion that was associated with the paper. As we shall soon see, it was corrosion that was to be the Achilles heel of the pipeline, and the battle against this corrosion was to be the main preoccupation of the operators of the pipeline from the early days of operations only a few years after commissioning.

An especially important item that does not appear in the design consideration or in the discussion, was the combination of a very brittle, barely-adherent, and unreinforced coating, with a method of making field joints that involved extensive hammering of the lead into the joint during the process of caulking.

Construction of the pipeline

The pipes were transported to the right-of-way by train, and where necessary by horse and cart as shown in figures 14 and 15.

Figure 26 A team of camels used for ploughing in the construction of one of the tanks for the pipeline (Courtesy Battye Library BA555-56)

The trenching and other excavation was done by hand tools after any necessary blasting. Wherever possible, the material to be taken out was loosened by horse or camel-drawn plough. A plough drawn by a team of camels is shown in figure 26.

The construction of the pipeline was undertaken in sections about 20km long. The gangs working on each section were equipped with two pipe lowering trestles, four skids, one pipe expander, one lead melter, and a mechanized caulking machine. Towards the end of the project, with seven gangs working, the overall rate of progress reached as much as 2km per day of laying, jointing and backfilling. A picture of the method of lowering-in is shown in figure 27.

Figure 27 Lowering the pipes into the trench. A bell hole for jointing is visible in the foreground [16].

Filling of the pipeline commenced in April 1902, and by August construction and filling was complete as far as the Merredin Tank at 225km. Water reached Coolgardie in December 1902, and Kalgoorlie in January 2003.

Living and working conditions in construction

An idea of the wages and salaries of the time is given by the following table:

person	£ annual salary circa 1900	$ (Australian 2002) (£ x 120)
C.Y. O'Connor (Chief Engineer)	1500	180,000
T.C. Hodgson (Engineer-in-charge)	600	72,000
Foreman* 15s. 6p./day	194	23,300
Tradesman* 12s. 6p./day	156	18,700
Labourer* 10s./day	125	15,000

*@ 250 days per annum

A permanent campsite was established at the Dam site at Mundaring by the Public Works Department. This had turned into a town with a school, a hotel, and shops by early in the construction period. Bush camps were established along the pipeline route to accommodate the workers. This was greatly helped by the proximity of the railway line and road. A picture taken in one of the bush camps is shown in figure 28.

Figure 28 A Sunday afternoon in one of the bush camps. Courtesy Battye Library 4384P.

Operation and maintenance of the pipeline

The quantity of water supplied to the Coolgardie and Kalgoorlie goldfields grew from about 2.7ML per day in 1905 to 10ML per day, i.e. a little under half the design capacity of 23ML per day, in 1911. Several years later in 1915, the total supply was 15ML per day, of which 3ML each was supplied to the mines near Southern Cross and the agricultural districts, and the remaining 9ML to Coolgardie and Kalgoorlie. According to projections made at that time, the full design capacity of 23ML/day would be reached in 1920, some 17 years after the pipeline was commissioned [18]. In fact the first time that the design capacity was exceeded was in 1943 [2].

The total population being supplied at this time was about 45,000 people. About 34,000 of these were in the goldfields. The price charged for the water was 4s. per thousand gallons at Kalgoorlie, which is £44/ML. Whilst this is a very low price compared to the prevailing cost of water prior to the building of the pipeline, it is a very high price compared to the price of irrigation water today. Using the escalation multiplier of 120 mentioned earlier in this paper, the price is equivalent to $5300/ML in 2002 Australian dollars.

Over this period very significant problems were experienced with both external and internal corrosion, and with the consequences of actions taken to mitigate the internal corrosion, notably the addition of lime to the water.

The reduction in flow caused by encrustation of the internal surface by corrosion nodules, and by the formation of lime deposits, both severely diminished the hydraulic capacity of the pipeline, and at the same time, steeply accelerating losses due to leakage threatened the capability of the pipeline to deliver the required volumes. It was fortunate that at this time the design had provided substantial reserve capacity so that it was still able to meet the demands imposed upon it.

The number of leaks from holes in the pipeline caused by external corrosion is shown in figure 29 for the early years of the operation of the pipeline [18]. The rate of leakage is shown in figure 30 [19].

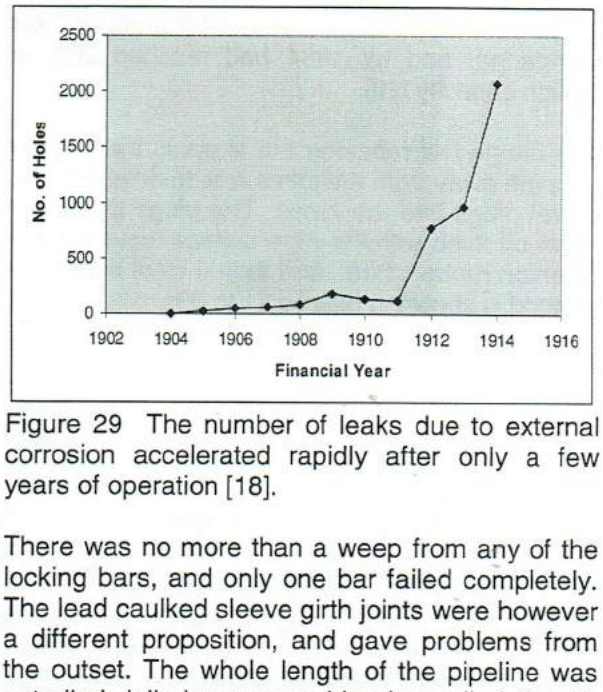

Figure 29 The number of leaks due to external corrosion accelerated rapidly after only a few years of operation [18].

There was no more than a weep from any of the locking bars, and only one bar failed completely. The lead caulked sleeve girth joints were however a different proposition, and gave problems from the outset. The whole length of the pipeline was patrolled daily by men on bicycles called "length runners". These men were stationed at about 15km intervals, and their bicycles were fitted out with a big leather bag fitted into the frame and filled with tools [20]. In the first 5 or so years the recaulking of the lead kept these people occupied for about half of their time. This recaulking work gradually diminished, but it was soon replaced by other activities as the effects of both internal and external corrosion began to be manifested. The constant hammering had a serious effect in hastening internal corrosion by shaking off the protective coatings [18].

Until 1914 most of the holes occurred as isolated pits, however the very rapid increase in leaks that occurred around that time was due to a change in the nature of the corrosion to large areas of scaling, especially in salt affected soils.

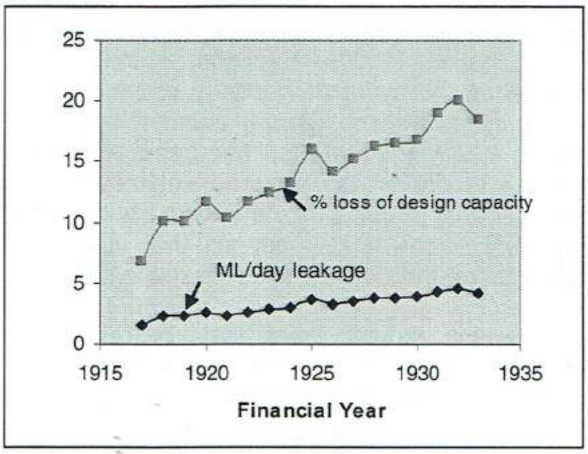

Figure 30 Losses due to leakage were in some years 15% or so of the total water pumped from Mundaring, and by 1934 had reached 20% of design capacity [19].

The method of repairing the leaks in the body of the pipe away from the joints was to drive wooden dowel plugs into the holes. The plugs were then sawn off flush with the pipe surface, covered with insertion rubber sheet, and then a steel band. The method is shown in figures 31 to 33.

Figure 31 The method of repairing leaks in the pipeline. Tapered wooden dowel plugs are being driven into the holes. A spray of water is visible in the photograph. The repair is directly adjacent to a sleeve joint. Courtesy WA Water Corporation.

Figure 32 A series of 20 or so tapered wooden dowel plugs driven into corrosion holes in the pipeline ready to be sawn flush. Courtesy WA Water Corporation.

Figure 33 The completed repair after covering the plugs with rubber and a bolted steel cover strap. Courtesy WA Water Corporation.

Very detailed consideration of the various factors affecting corrosion; the quality of the coating and lining, the decision to bury the pipeline, the exposure of the coated pipes to the elements for up to two years prior to burial, and many other aspects are given in the references, especially references 18 and 19. The efficacy of the novel methods of corrosion mitigation using lime treatment and (subsequently) de-aeration treatment of the water are particularly interesting.

Although the merits of the lead joint receive a great deal of discussion, no attention is given to the likelihood that the joint contributed to corrosion by galvanic effects.

Wood stave pipe

In the 1930s it became very difficult to obtain steel pipe to replace badly corroded sections, and as a result of this, some sections of the pipeline were replaced with wood stave pipe. About 64km of this pipe was installed in the main Coolgardie pipeline between 1933 and 1937. The pipe was manufactured by the Australian Wood Pipe Company which established a factory in Perth for the purpose [21].

The pipe was made from Eucalyptus diversicolor (Karri) and later from Eucalyptus wandoo (Wandoo) because of its better durability. The Karri was sawn into 127 x 38mm staves which were *"Fluarised"* by boiling them in a solution of sodium dinitrophenate, sodium fluoride, and arsenic trioxide. This treatment penetrated about 15mm into the surface of the wood and gave protection against fungal and termite attack [22]. The staves were then sawn into two 127 x 19mm pieces for use in making the pipe so that the untreated surfaces were on the inside exposed to the water. The pipes were assembled in the same way as a Cooper would make a wine barrel, and were bound with galvanized steel wire before dipping into tar and bitumen for corrosion protection.

The life of the wood stave pipe was between 20 and thirty years. The last wood stave pipe was replaced in 1971. A photograph of a remnant of the pipe is shown in figure 34.

The wood stave pipe was not popular with the pipeline operators because of very high leakage rates when being commissioned whilst the timber was still swelling, and because of high ongoing maintenance costs.

The Wandoo pipe gave much superior performance to Karri. This reflects the better durability of the former timber. The CSIRO durability rating of Wandoo is 1 for both decay and termites, whilst for Karri it is 3 and 4 respectively [23].

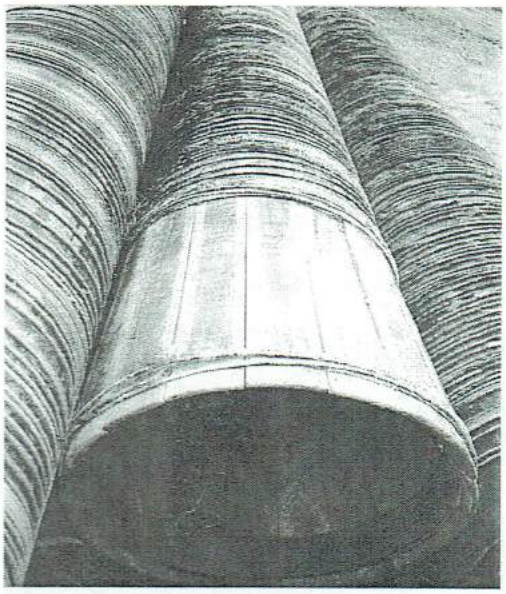

Figure 34 A photograph of wood stave pipe remnants from the Coolgardie pipeline. Courtesy Fred Shelley, 2002.

Rehabilitation of the pipeline

In the period 1933/34 the maintenance costs of the pipeline began to rise to an unacceptable level. This was partly due to an increase in the number of leaks and bursts, but it was also due to some restoration in wage levels as the Great Depression came to an end. Included in the maintenance costs was the need for a special rail motor trolley to inspect the pipeline at night when no trains were running so as to protect railway traffic from washaways due to bursts [19].

It was concluded at this time that the lead joints were unsatisfactory, and that they needed to be replaced. It was also found necessary to properly protect the inside and outside of the pipeline against corrosion. So in order to secure the long term service of the pipeline (and by this time it had been demonstrated to everybody's satisfaction that it was necessary to maintain the pipeline in service), it was decided to raise the entire pipeline above ground, to line the inside of the pipes with cement mortar, and to replace all of the leaded sleeve joints with welded joints.

These activities were described in 1935 by Fernie and Keating in [19]. They predicted that when the main was continuously welded from Mundaring to Kalgoorlie that the total leakage rate would be reduced to less than 0.25ML/day, and that the renovated main should have a life of at least 50 years.

These predictions turned out to be well and truly justified since in 2002 the pipeline is still in operation.
The steam pumps were replaced by electric units in the 1950s.

A photograph of a section of the line in operation in 2002 is shown in figure 35. Over 50% Of the original pipes are believed to be still in service. The section shown in figure 35 has been duplicated with new pipe laid alongside the old. The old pipe is heavily patched.

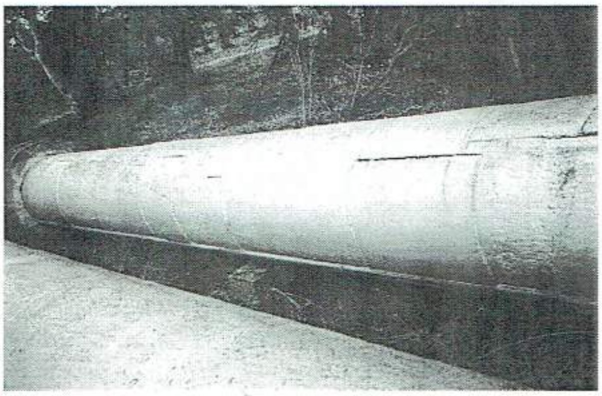

Figure 35 A section of the pipeline in operation in 2002 nearly 100 years after the pipeline was commissioned in 1903. A new section of pipeline has been laid to duplicate the old line and increase its capacity. The old pipe is heavily patched. Courtesy Fred Shelley.

No comprehensive cost/benefit analysis of the pipeline over its lifetime has been found. No doubt such analyses have been performed at various times, but they have not come to light in the references to hand. There are substantial and widespread agricultural enterprises serviced by the pipeline which it seems would have been unlikely to have existed without the water, and which importantly would not have either collectively or individually justified the investment in the pipeline.

And of course there is the gold. Again, the precise amount of gold recovered from the fields serviced by the pipeline has not been discovered, however in 1964 Casey and Mayman [24] reported that in the 70 years since the first shafts were sunk at Kalgoorlie, that in that precinct alone, some 33 million ounces of gold had been recovered. The value of that gold in 2002 is around $20 billion Australian. On that basis, the total amount of gold recovery that was enabled by the pipeline from all of the mines it served up until the present time might at a guess approach $50 billion.

Against these figures the initial capital investment of $300m 2002 Australian dollars seems very small.

A most important observation from the standpoint of modern times is that the pipeline was principally built as an act of faith driven by the imagination and foresight of John Forrest and the capability of his personal appointee to the position of Chief Engineer, C.Y. O'Connor. There was much opposition to the scheme, and to the chosen design capacity. The design capacity was indeed greater than was required at the time of commissioning, and for quite a long time after. However the reserve capacity did get taken up, and it did provide an infrastructure resource for further development in the areas that it served. And there is no doubt that much of that development would not have happened if each new chunk of demand had needed to justify incremental increases in pipeline capacity.

There is a lesson in this for us in 2002 when almost all infrastructure development depends upon private investment, and when the rate of return on such investments is regulated in a manner which is presently acknowledged not to favour such investment. This has led to a situation where pipelines for which there is a justifiable community need are not being built, and when they are built, they do not provide adequately for future growth.

The death of CY O'Connor

The inspired engineer of this innovative project was subject to severe criticism and pressure by some community groups, the parliamentary opposition, and the press. He also felt the burden of over-work, and the absence of his friend and champion, Sir John Forrest who had moved into Federal politics. These pressures led him to take his own life at the age of 59 on the shore of Fremantle beach on the morning of March 10th 1902.

This was just a few days after he had watched water successfully pumped from the Mundaring weir to number 2 receiving tank.

O'Connor attracted a great deal of criticism from people who were opposed to his policy of undertaking most of the work within the Public Works Department rather than using private contactors, and there were many suggestions that he made improper use of his position. However he was totally exonerated of any misdoing in an inquiry held after his death, and in fact at the time he died, his total assets amounted to less than £200.

He did not commit suicide on the basis of any suggestion or apprehension that the scheme had in some way failed to perform to design or expectation as was widely believed in popular myth.

Acknowledgements

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